VEGETATION HEALTH OF PIONEER SPECIES IN THE NATURAL SUCCESSION OF A BURNED PEATLAND ECOSYSTEM IN LIANG ANGGANG

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ABSTRACT. *Peatland forests in Liang Anggang, Banjarbaru City, play a vital ecological role as carbon sinks, hydrological regulators, and biodiversity buffers. However, these ecosystems are highly vulnerable to recurrent fires, which occur almost annually. Repeated fire events have led to vegetation degradation, declining ecosystem health, and reduced peat capacity to retain water, maintain soil moisture, and support the regeneration of native vegetation. These conditions elevate the risk of ecological disasters and carbon emissions, highlighting the need for vegetation health assessments as a foundation for sustainable restoration strategies.This study evaluated post-fire vegetation health using the Forest Health Monitoring (FHM) approach. The results indicate that the most severe damage occurred in leaves (72%), followed by damage to shoots and buds (11%), and to both upper and lower stems (4–5%). The most common types of damage were leaf and shoot damage (34%) and leaf discoloration (26%), reflecting physiological stress due to increased temperatures and reduced soil moisture after fire events. Damage severity was predominantly classified as light to moderate (10–29%), accounting for 81% of all observed cases.The pioneer vegetation identified includes galam (Melaleuca cajuputi) and acacia (Acacia sp.), which play a significant role in the early stages of ecological succession, although the regeneration of native peatland species remains limited. Overall, vegetation health was categorized as healthy (94%), indicating a strong potential for ecosystem recovery, particularly if hydrological conditions can be effectively maintained. These findings provide a scientific basis for developing sustainable conservation and restoration strategies for the Liang Anggang peatland forest.*

Keywords: *Peatland forest; Forest Health Monitoring (FHM); Vegetation damage; South Kalimantan*

ABSTRAK. Hutan gambut di Liang Anggang, Kota Banjarbaru memiliki fungsi ekologis penting sebagai penyimpan karbon, pengatur tata air, serta penyangga keanekaragaman hayati, namun rentan terhadap kebakaran yang hampir terjadi setiap tahun. Frekuensi kebakaran menyebabkan degradasi vegetasi, menurunnya kesehatan ekosistem, dan berkurangnya kemampuan gambut dalam menahan air, menjaga kelembaban tanah, serta mendukung regenerasi vegetasi khas. Kondisi ini meningkatkan risiko bencana ekologis serta emisi karbon, sehingga diperlukan kajian kesehatan vegetasi sebagai dasar untuk upaya restorasi berkelanjutan. Penelitian ini menilai kesehatan vegetasi pascakebakaran menggunakan metode Forest Health Monitoring (FHM). Hasil analisis menunjukkan bahwa kerusakan tertinggi terjadi pada bagian daun (72%), diikuti kerusakan pucuk dan kuncup (11%), serta kerusakan batang atas dan bawah (4–5%). Tipe kerusakan paling umum berupa kerusakan daun dan pucuk (34%) serta perubahan warna daun (26%) yang menggambarkan stres fisiologis akibat peningkatan suhu dan penurunan kelembapan tanah pascakebakaran. Tingkat keparahan kerusakan didominasi kategori ringan hingga sedang (10–29%) sebesar 81% dari keseluruhan kejadian. Vegetasi pionir yang muncul terdiri atas Galam (*Melaleuca cajuputi*) dan Akasia (*Acacia* sp.) yang berperan dalam fase awal suksesi meskipun regenerasi spesies asli gambut masih terbatas. Tingkat kesehatan vegetasi secara umum berada pada kategori sehat (94%), menunjukkan potensi pemulihan ekosistem yang kuat apabila kondisi hidrologi dapat dipertahankan. Temuan ini memberikan dasar ilmiah bagi strategi konservasi dan restorasi hutan gambut Liang Anggang secara berkelanjutan.

Kata kunci: Hutan gambut; Forest Health Monitoring (FHM); Kerusakan vegetasi; Kalimantan Selatan

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INTRODUCTION

Peatland forests are ecosystems with a crucial role in maintaining environmental balance, particularly through their capacity to store large amounts of carbon, regulate hydrological systems, and serve as habitats for diverse flora and fauna. These ecosystems also function as buffers against global climate change through carbon sequestration and storage mechanisms (Beaulne et al., 2021). Despite their high ecological value, peatlands are highly vulnerable to disturbances, especially due to land-use changes and increasing fire intensity (Carroll et al., 2023). According to Adinugroho (2004, as cited in Kusuma et al., 2021), forest and land fires are natural or anthropogenic events characterized by the spread of fire that consumes fuel within forest and land areas.

In Indonesia, particularly in South Kalimantan, peatland fires occur almost annually, driven by land-clearing activities and the high flammability of peat during the dry season. Data from the Badan Nasional Penanggulangan Bencana (BNPB) in 2023 recorded 802 forest and land fire incidents across Indonesia between January 1 and November 4, 2023. South Kalimantan was among the most severely affected provinces, with a total burned area reaching 138,865.87 hectares.

The Liang Anggang Protected Forest area in Banjarbaru represents one of the peatland regions experiencing significant ecological pressure. Recurrent fires occur almost every year due to land openness, peat drainage, and the highly combustible nature of dry peat during the dry season. Once dried, peat becomes a highly flammable fuel source (Forest and Land Fire Laboratory, IPB, 2018). These disturbances reduce vegetation quality, accelerate canopy degradation, weaken natural regeneration, and diminish the ecosystem's hydrological and ecological functions. Consequently, such degradation contributes to increased flood risks, carbon emissions into the atmosphere, and the loss of biodiversity buffering capacity.

Covering approximately 2,250 hectares, the Liang Anggang Protected Forest is categorized as a high fire-frequency area. Repeated fires have led to vegetation loss, decreased biodiversity, reduced carbon sequestration capacity, and disrupted hydrological functions. Post-fire conditions are typically associated with increased soil bulk density and reduced soil moisture content (Hermanto & Wawan, 2017). Fires also alter soil chemical properties, including increased pH levels and decreased organic carbon content (Lubis, 2016).

The native species of peatland forests have experienced significant population declines. Natural succession following fire disturbances depends heavily on the presence of pioneer species that contribute to soil structure improvement, organic matter accumulation, and the creation of favorable microclimatic conditions for the growth of other species. Ecosystem recovery through natural succession is a critical process in restoring ecological functions and biodiversity in degraded areas, such as those affected by fire or deforestation. According to Sutedjo (2021), forests disturbed by fire generally undergo secondary succession, beginning with the growth of pioneer vegetation such as grasses and shrubs, and gradually developing into more complex structures until reaching a climax stage characterized by the emergence of new trees and the formation of secondary forests. Fires often result in the mass mortality of fire-sensitive species, leaving behind only fire-resistant or introduced species that drive natural regeneration processes (Marlina, 2017).

Forest health monitoring is therefore essential to assess the extent of vegetation damage in peatland ecosystems. Forest Health Monitoring (FHM) is a systematic approach used to monitor, assess, and report the current status, changes, and long-term trends in forest ecosystem health using measurable ecological indicators. The FHM approach enables a comprehensive evaluation of vegetation health through the assessment of damage location, damage type, and severity across different plant parts. Such information is critical for informing conservation strategies, forest management, and sustainable peatland restoration efforts. This study aims to assess the post-fire vegetation health condition of peatland forests in Liang Anggang, providing scientific evidence to support ecosystem protection and restoration initiatives in South Kalimantan.

METHODS

Study Area, Materials, and Equipment

This study was conducted over approximately three months in a post-fire peatland forest within the Liang Anggang Protected Forest area, Banjarbaru City, South Kalimantan, Indonesia (Figure 1). The research activities included field data collection, data processing, and report preparation.

The equipment used in this study consisted of a location map, machete, measuring tape, raffia string, meter ruler, timestamp device, calculator, writing tools, tally sheets, and a smartphone equipped with Avenza Maps and PlantSnap applications, as well as a hagameter and a laptop for data analysis. The objects of this study were vegetation at the seedling, sapling, pole, and tree growth stages within the study area.

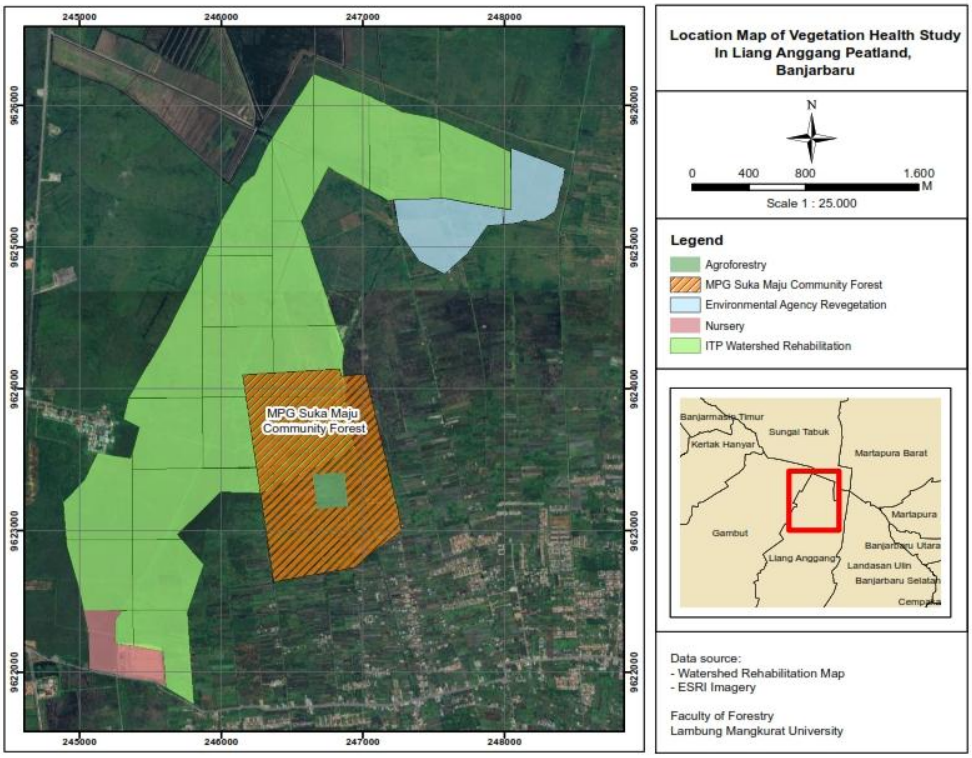


Figure 1. Study Area Map

Research Procedure

Vegetation data in the peatland area were collected using two main plots, each measuring 60 × 60 m. Sampling was conducted using nested plots of different sizes based on vegetation growth stages:

- 20 × 20 m for tree level
- 10 × 10 m for pole level
- 5 × 5 m for sapling level
- 2 × 2 m for seedling level

The number of plots established in this study was determined based on considerations of field representativeness and the suitability of the applied method. The use of two main plots measuring 60 × 60 m was considered sufficient to represent the relatively homogeneous condition of post-fire peat swamp forest vegetation at the study site. Although the number of plots was limited, the observation intensity was carried out comprehensively through the application of nested subplots (20 × 20 m, 10 × 10 m, 5 × 5 m, and 2 × 2 m) designed to accommodate different vegetation growth stages, thereby ensuring that the collected data remained comprehensive. This approach is also consistent with the Forest Health Monitoring (FHM) method, which emphasizes detailed observations of individual vegetation based on damage indicators. Therefore, the number of plots used in this study was considered adequate to accurately and efficiently describe the vegetation health condition.

All observations were recorded in prepared tally sheets for subsequent data analysis. Each sample plot documented the plant species present along with the number of individuals per species. Vegetation identification within each plot was classified based on growth criteria, as follows:

1. Seedlings: germinated plants up to young individuals with a height of less than 1.5 m.
2. Saplings: individuals with a height ≥1.5 m and diameter <10 cm.
3. Poles: individuals with a diameter of 10 cm to <20 cm.
4. Trees: individuals with a diameter ≥20 cm (Dimara & Auri, 2023).

Vegetation Health Assessment

Vegetation health was assessed using the Forest Health Monitoring (FHM) method. Each observation plot was initiated by establishing a tie point to facilitate future monitoring of forest health indicators. Forest vitality assessment was carried out through direct observation, field measurements, and evaluation of damage conditions for each individual tree or pole. Vegetation damage was assessed based on the location of damage, type of damage, and severity level, following the FHM protocol. The identified damage data were coded and matched with weighted index values to calculate the vegetation damage index. The damage index was calculated using the formula proposed by Mangold (1997) (Apriani et al., 2022):

$$\text{Damage Index (DI)} = (X_1 \times Y_1 \times Z_1) + (X_2 \times Y_2 \times Z_2) + \ldots + (X_n \times Y_n \times Z_n) \quad (1)$$

Where:

- X = Location of damage
- Y = Type of damage
- Z = Severity level

The Area-Level Index (ALE) was calculated as the average tree damage within a given area. Furthermore, vegetation damage levels were classified into four categories based on the damage index, as presented in Table 1.

Table 1. Tree Health Categories Based on Damage Index Values

Tree Health Category	Damage Index Value
Healthy	0-5
Minor damage	6-10
Moderate damage	11-15
Severe damage	≥ 16

RESULTS AND DISCUSSION

The assessment of peatland vegetation health was conducted using three key variables within the Forest Health Monitoring (FHM) framework: damage location, damage type, and damage severity. These variables were applied to quantitatively determine the level of vegetation damage (Martiansyah et al., 2022). Damage location refers to the specific plant parts affected—such as leaves, stems, buds, or shoots—and serves as an early indicator of physiological stress in vegetation (Pertiwi et al., 2019). The distribution of observed damage locations is presented in Table 2.

Table 2. Identification of Damage Location in Peatland Forest Vegetation

Damage Location	Percentage of Damage (%)	Number of Cases
No damage	8	30
Lower and upper stem	4	14
Upper stem	5	20
Buds and shoots	11	39
Leaves	72	263

Based on the identification of vegetation damage locations presented in Table 2, the distribution of damage shows a clear dominance in the leaf component, accounting for 72% (263 cases). This finding indicates that leaves are the most vulnerable plant organs to environmental stress compared to other parts. From a plant physiological perspective, leaves play essential roles in photosynthesis, respiration, and transpiration, making them the first organs to respond to environmental changes. Leaf damage is often associated with abiotic stress factors such as increased temperature, fluctuations in humidity, and drought, as well as biotic stress caused by pests and pathogens (Safe'i et al., 2024; Safe'i & Machya, 2016).

The dominance of leaf damage observed in this study is consistent with recent findings in coastal ecosystems. For instance, a study published in the Biodiversitas Journal reported that vegetation damage in mangrove ecosystems was also dominated by leaf damage (35%), closely linked to environmental pressures and ecosystem dynamics (Susilawati et al., 2026). Although the percentage reported in this study is substantially higher (72%), the similar pattern reinforces the role of leaves as sensitive indicators of ecosystem degradation across different ecosystems, including peatlands and mangroves. The high proportion of leaf damage in this study can be interpreted as a strong signal that peatland vegetation remains under ecological stress, particularly in post-fire conditions characterized by altered microclimates, reduced soil moisture, and increased solar radiation intensity.

Damage to buds and shoots accounted for 11% (39 cases), indicating disturbances in meristematic tissues responsible for vegetative growth. Although quantitatively lower than leaf damage, ecologically, damage to these parts has more serious implications for vegetation sustainability. Buds and shoots are key indicators of natural regeneration; therefore, disturbances in these structures may hinder the formation of new organs and slow down ecosystem recovery processes. Within the Forest Health Monitoring (FHM) framework, damage to regenerative tissues is often associated with reduced stand vitality and limited adaptive capacity to environmental stress (Gandadipoera et al., 2024).

Meanwhile, damage to the stem—both upper (5%) and combined lower and upper sections (4%)—reflects structural disturbances within the vegetation. Although the proportion is relatively small, stem damage has long-term implications for plant stability and survival. The stem functions as both a structural support and a conduit for water and nutrient transport; thus, damage to this part can disrupt resource distribution throughout the plant. Previous studies have shown that stem damage, such as open wounds, cracks, and decay, serves as a critical indicator in assessing tree health due to its potential to increase mortality risk and reduce ecosystem productivity (Safe'i et al., 2024; Safe'i & Machya, 2016).

The proportion of vegetation with no observed damage was only 8% (30 cases), indicating that the majority of vegetation has been affected by disturbance. This low percentage suggests that overall vegetation health remains suboptimal. In large-scale forest health monitoring studies, a stable ecosystem is typically characterized by a dominance of healthy trees, whereas an increasing proportion of damaged vegetation reflects significant environmental pressure (Porter et al., 2023). Therefore, the low proportion of undamaged vegetation in this study strengthens the indication that the peatland ecosystem is still in a degraded or unstable recovery phase.

Overall, the analysis of Table 2 demonstrates that the distribution of damage is uneven across plant organs, with the highest concentration occurring in leaves as the primary physiological organ. This pattern suggests that environmental stress initially affects physiological functions before progressing into more severe structural damage. Furthermore, the combination of high leaf damage and a low proportion of healthy vegetation indicates that the peatland ecosystem remains vulnerable. This finding aligns with recent developments in forest health monitoring approaches, which emphasize the integration of visual indicators—such as damage location—with advanced technologies, including UAVs and machine learning, to enable early and accurate detection of vegetation stress (Ecke et al., 2024).

In conclusion, the findings of this study confirm that damage location—particularly in leaves—serves as a key indicator in assessing the health of peatland forest vegetation. The high level of leaf damage, accompanied by damage to both regenerative and structural organs, indicates

that the vegetation has not yet fully recovered from environmental disturbances. Therefore, more intensive management and rehabilitation efforts are required, along with continuous monitoring using the Forest Health Monitoring (FHM) approach, to ensure optimal ecosystem recovery.

Table 3. Identification of Damage Types in Peatland Forest Vegetation

Damage Type	Percentage of Damage (%)	Number of Cases
No damage	8	30
Open wounds	8	30
Loss of shoots / dead shoots	10	37
Leaf or shoot damage	34	125
Leaf discoloration	26	94

Table 3 presents the variation in vegetation damage types, which can be used as indicators of ecosystem health based on the Forest Health Monitoring (FHM) framework. Within this approach, damage type is a critical parameter as it reflects vegetation responses to environmental stress, both physiological and structural in nature (Martiansyah et al., 2022).

Based on Table 3, vegetation damage is dominated by leaf or shoot damage, accounting for 34% (125 cases). This finding indicates that photosynthetic components are the most vulnerable to environmental disturbances. Ecologically, leaves and shoots are organs with high metabolic activity, making them highly sensitive to changes in environmental conditions such as temperature, humidity, and water availability. This result is consistent with findings from studies in coastal ecosystems, including research published in the Biodiversitas Journal, which reported that vegetation damage in mangrove ecosystems is also predominantly observed in leaves as a response to environmental pressure and habitat changes (Susilawati et al., 2026). This consistency reinforces the role of leaves as sensitive indicators of vegetation health across different ecosystem types, including peatlands.

The second most common damage type is leaf discoloration, accounting for 26% (94 cases). Symptoms such as chlorosis (yellowing) and necrosis (blackening) are widely recognized as indicators of physiological stress in plants. These conditions are often associated with nutrient deficiencies (particularly nitrogen and magnesium), impaired water uptake, or root system disturbances caused by unstable soil conditions. In post-fire peatland ecosystems, leaf discoloration may also result from increased surface temperatures, oxidation of organic matter, and reduced nutrient availability due to soil degradation (Latumahina et al., 2024). Furthermore, studies in the International Journal on Advanced Science Engineering and Information Technology highlight that leaf discoloration serves as an early indicator of declining vegetation health, often preceding more severe structural damage (Gandadipoera et al., 2024).

Damage in the form of loss of shoots or dead shoots was recorded at 10% (37 cases). This type of damage has significant ecological implications, as shoots represent the apical growth points that determine the direction and rate of vegetative growth. The loss of shoots can hinder the formation of new branches, reduce canopy expansion, and limit the plant's ability to compete for light. Over time, this condition may slow vegetation regeneration and alter plant community structure. Recent studies indicate that damage to meristematic tissues is often associated with chronic environmental stress, such as prolonged drought or exposure to extreme temperatures—conditions commonly observed in degraded peatland ecosystems (Safe'i et al., 2024).

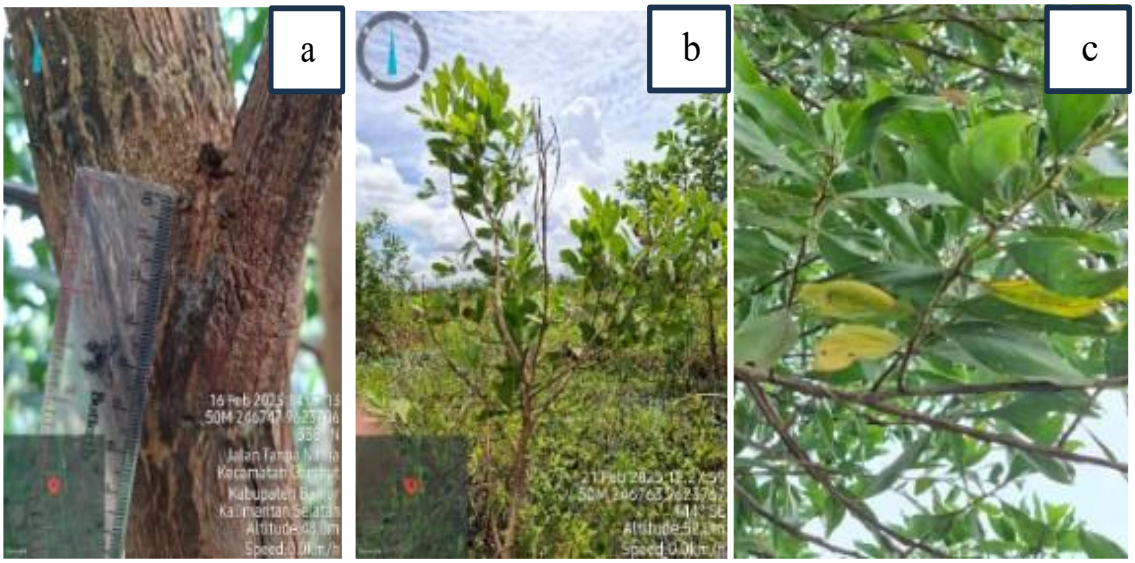
Meanwhile, open wounds were observed in 8% (30 cases). These wounds, occurring on stems or branches, may result from mechanical disturbances such as wind, falling debris, animal activity, or human intervention. Open wounds can act as entry points for pathogens, including fungi and bacteria, which may accelerate decay processes and reduce plant vitality. Within the FHM framework, open wounds are

classified as structural damage which, although not dominant in percentage, can significantly affect long-term plant survival (Safe'i & Machya, 2016).

The proportion of vegetation with no observable damage was also 8% (30 cases), indicating that only a small fraction of the plant community remains in a healthy condition. This low proportion suggests that most vegetation in the study area has been exposed to environmental stress. In stable ecosystems, healthy vegetation typically dominates, whereas a high proportion of damaged individuals reflects substantial ecological pressure (Porter et al., 2023).

Overall, the distribution of damage types in Table 3 indicates that vegetation damage is primarily characterized by physiological symptoms affecting leaves and shoots, which represent early responses to environmental stress. This pattern suggests that disturbances have not yet fully progressed into severe structural damage but have already affected fundamental plant functions, particularly photosynthesis and growth. Symptoms such as leaf yellowing, drying, and shedding may result from multiple stressors, including high salinity, environmental pollution, pest and disease attacks, hydrological stress (flooding or drought), and nutrient-poor degraded peat soils (Latumahina et al., 2024; Susilawati et al., 2026).

In conclusion, the identification of damage types confirms that the peatland forest ecosystem in the study area remains under significant ecological stress. The dominance of leaf and shoot damage indicates that environmental pressures primarily affect plant physiological processes, which, if left unmanaged, may progress into more severe structural damage. Therefore, targeted management strategies are required, focusing on environmental restoration—such as hydrological rehabilitation, soil fertility improvement, and biotic stress control—to support sustainable vegetation recovery.



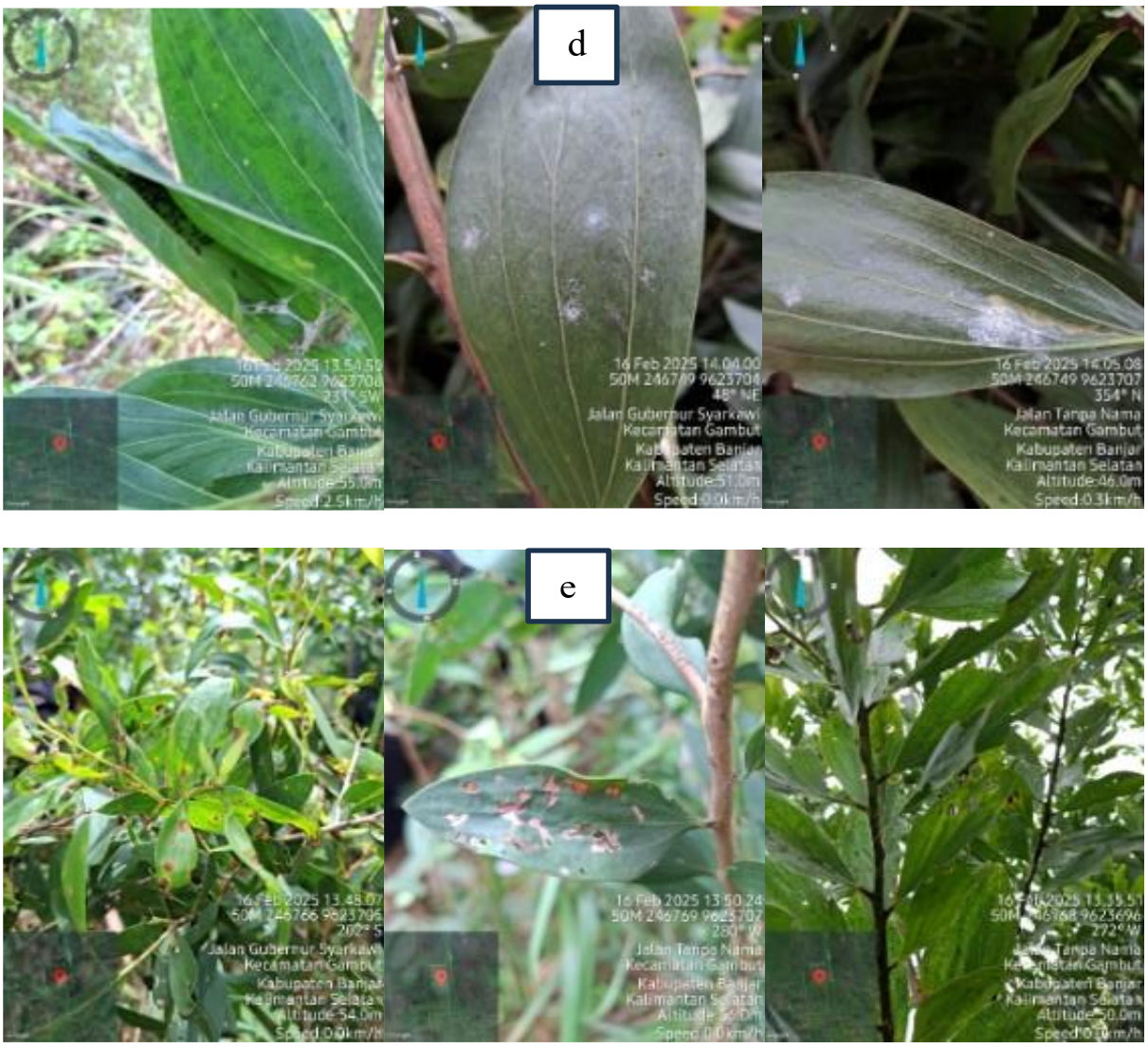


Figure 2. Types of Damage Observed in the Liang Anggang Peatland Forest: (a) Open wounds; (b) Loss of shoots; (c) Leaf discoloration; (d) Animal activity; (e) Leaf damage

Vegetation damage observed in the Liang Anggang peatland forest reflects a range of biotic and abiotic pressures that influence the natural succession process. Open wounds on stems or branches indicate mechanical disturbances caused by fire, human activities, or other environmental factors. These injuries can disrupt water and nutrient transport systems and may serve as entry points for pathogens, thereby reducing plant vitality. The loss of shoots suggests impairment of apical growth, which is commonly associated with herbivory or environmental stress, and may consequently limit plant height growth and branching development. Leaf discoloration represents a physiological indicator of stress, often resulting from nutrient deficiencies or environmental constraints characteristic of peatland ecosystems. Such conditions can reduce photosynthetic efficiency and overall plant productivity. Evidence of animal activity, including feeding marks, holes, and tissue damage, directly reduces plant biomass and may increase susceptibility to secondary infections. Meanwhile, leaf damage in the form of tears, perforations, or necrotic tissue reflects both physical and biological stressors that further diminish photosynthetic performance. Overall, the damage symptoms illustrated in Figure 2 indicate that post-fire peatland vegetation is exposed to multiple sources of stress. However, the presence of damage alone does not necessarily reflect the actual health condition of the vegetation. Within the Forest Health Monitoring (FHM) framework, the severity of damage is a crucial factor in determining its impact on plant vitality. Therefore, the distribution of

damage severity levels was further analyzed and is presented in Table 4.

Table 4. Identification of Damage Severity Levels in Peatland Forest Vegetation

Severity Level (%)	Percentage (%)	Number of Cases
1-9	8	30
10-19	43	158
20-29	38	138
30-39	11	40

Table 4 presents the distribution of vegetation damage severity based on the Forest Health Monitoring (FHM) approach, which evaluates the intensity of damage as a quantitative indicator of vegetation health. Within the FHM framework, severity level is a critical parameter as it reflects the extent to which disturbances have affected both physiological and structural functions of plants (Martiansyah et al., 2022).

Based on Table 4, the most dominant severity level falls within the 10–19% category, accounting for 43% (158 cases). This indicates that the majority of vegetation experiences low to moderate damage. Ecologically, this level is typically characterized by early signs of physiological stress, such as reduced photosynthetic efficiency, leaf discoloration, and partial tissue damage, without directly causing plant mortality. These conditions suggest that vegetation still retains a certain level of adaptive capacity and resilience to environmental stress, particularly if the underlying disturbance factors can be mitigated (Safe'i et al., 2024; Safe'i & Machya, 2016).

The 20–29% severity category represents the second largest proportion at 38% (138 cases), indicating that a significant portion of vegetation has experienced more substantial impacts. At this level, damage extends beyond physiological stress and begins to affect plant structure, including partial canopy loss, shoot damage, and reduced regenerative capacity. The relatively high proportion in this category reflects considerable environmental pressure on the peatland ecosystem, affecting vegetation condition at a broader scale. Studies published in the International Journal on Advanced Science Engineering and Information Technology highlight that increasing severity levels are strongly associated with declining ecosystem productivity and reduced natural recovery capacity, particularly in degraded landscapes (Gandadipoera et al., 2024).

Meanwhile, the 30–39% severity category accounts for only 11% (40 cases), indicating that vegetation experiencing relatively severe damage remains limited. This low proportion suggests that, despite significant environmental stress, most vegetation has not yet reached critical or irreversible levels of damage. This condition is important from a management perspective, as vegetation with moderate damage still has a substantial opportunity for recovery through natural regeneration or targeted restoration interventions.

The lowest severity category, 1–9%, accounts for 8% (30 cases), representing vegetation with minimal disturbance and relatively healthy conditions. However, the small proportion of this category indicates that only a limited fraction of vegetation remains in optimal condition. In stable ecosystems, low-severity damage typically dominates; therefore, the distribution observed in Table 4 reflects a system that is still under ecological stress.

Overall, the severity distribution demonstrates a clear dominance of low to moderate damage levels, with a relatively small proportion of severe damage. This pattern suggests that the peatland forest ecosystem in the study area is currently in a post-fire recovery phase, where vegetation has been affected but has not entirely lost its capacity for regeneration. This finding is consistent with studies on mangrove ecosystem health, including research reported in the Biodiversitas Journal, which indicate that ecosystems under environmental pressure are typically dominated by low to moderate damage levels before progressing to severe degradation if

no management interventions are implemented (Susilawati et al., 2026).

In the context of peatland ecosystems, damage severity is closely linked to hydrological conditions. Lower groundwater levels lead to drier peat, increasing susceptibility to oxidation and fire, which in turn exacerbates vegetation damage. Therefore, peatland ecosystem recovery is highly dependent on restoring hydrological function, particularly through rewetting strategies. Measures such as canal blocking and improved water management have been shown to enhance soil moisture, reduce fire risk, and support natural vegetation regeneration (Ministry of Environment and Forestry, 2015; Page et al., 2022).

In conclusion, the severity analysis indicates that although vegetation damage is widespread, it is predominantly within a recoverable range. This provides a critical opportunity for implementing effective management and restoration strategies to accelerate ecosystem recovery.

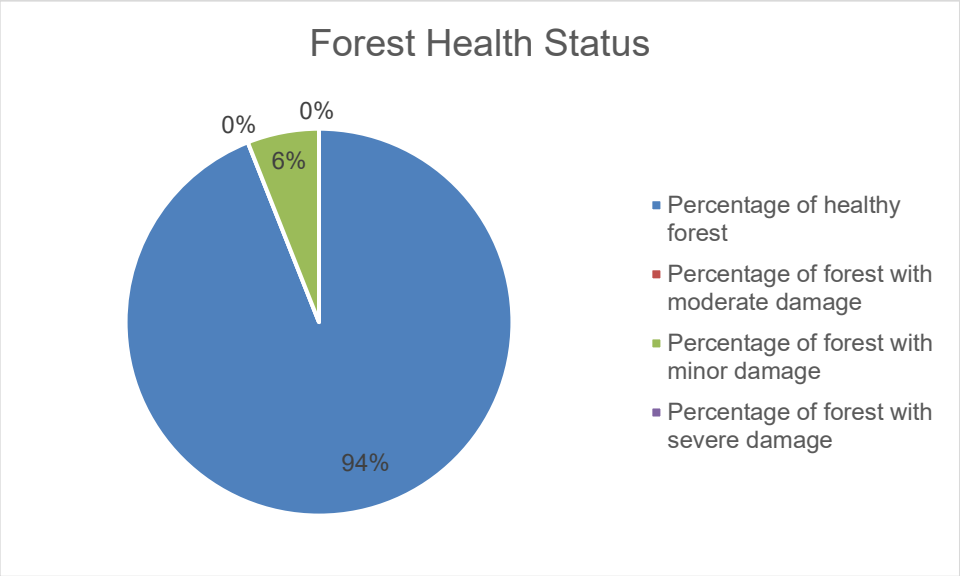


Figure 3. Percentage of Forest Damage Levels

At first glance, the high proportion of leaf damage (72%) and the low percentage of undamaged vegetation (8%) appear inconsistent with the finding that 94% of vegetation was classified as healthy. However, within the Forest Health Monitoring (FHM) framework, vegetation health status is not determined solely by the presence or frequency of damage symptoms. Instead, the final health classification is based on the Damage Index (DI), which integrates damage location, damage type, and damage severity. Consequently, vegetation may exhibit visible damage symptoms, particularly on leaves, while still being categorized as healthy if the damage is limited in severity and does not substantially affect overall plant vitality. In this study, most damage occurred in leaves and was predominantly classified within the low to moderate severity classes (10–29%), resulting in relatively low DI values. Therefore, despite the widespread occurrence of damage symptoms, the majority of vegetation remained within the healthy category according to the FHM classification system.

Figure 3 illustrates the distribution of vegetation health status, showing that the condition is overwhelmingly dominated by the healthy category (94%), while minor damage accounts for only 6%, and no cases of moderate or severe damage were recorded. These results suggest that, overall, the vegetation is in a relatively stable condition with minimal physiological and structural disturbances.

The dominance of the healthy category indicates that most vegetation individuals do not exhibit significant damage. However, when compared with the severity distribution presented in Table 4, it becomes evident that although the vegetation is generally classified as healthy, some individuals have already shown symptoms of low to moderate damage. This condition reflects the presence

of latent environmental stress that has not yet progressed into severe damage.

The 6% of minor damage represents early symptoms such as small wounds, slight changes in leaf morphology, or minor tissue disturbances. Although these symptoms do not yet significantly affect plant vitality, they may develop into more serious damage if environmental pressures persist. The absence of moderate and severe damage categories indicates that major structural degradation has not occurred, such as large stem breakage, severe pest infestations, or extensive tissue mortality.

Ecologically, the combination of a high proportion of healthy vegetation and the presence of minor damage suggests an ecosystem that is relatively stable but still vulnerable to disturbance. Recent studies emphasize that ecosystems appearing visually healthy may still harbor underlying ecological stress that can reduce vegetation health over time if not properly managed (Ecke et al., 2024).

In summary, while the current condition of the peatland forest vegetation indicates a strong recovery potential, the presence of early-stage damage highlights the importance of continuous monitoring and proactive management to prevent further degradation and to sustain long-term ecosystem resilience.

CONCLUSION AND RECOMMENDATIONS

Conclusion

The health condition of peatland forest vegetation indicates that the stand structure remains affected by fire disturbances, with damage predominantly occurring in leaves as a key indicator of physiological stress. The dominance of low to moderate damage levels suggests that the ecosystem is in the early stage of ecological recovery. The presence of pioneer species such as Melaleuca cajuputi (galam) and Acacia sp. confirms that natural succession processes are underway, although the regeneration of native peatland species remains limited. Overall, vegetation condition falls within the healthy category, demonstrating a strong potential for natural recovery, particularly if hydrological conditions are effectively maintained.

Recommendation

Based on the findings of this study, it is recommended that peatland ecosystem management prioritize hydrological restoration through rewetting strategies, such as canal blocking and water table control, to maintain soil moisture and reduce fire risk. In addition, enrichment planting with native peatland species should be implemented to support natural succession and enhance biodiversity, particularly in areas with limited regeneration. Continuous monitoring using the Forest Health Monitoring (FHM) approach is essential to detect early signs of vegetation stress, and its integration with advanced technologies such as remote sensing and UAVs can improve monitoring accuracy. Efforts to minimize fire recurrence and human disturbance should also be strengthened through community-based management and effective land-use control. Furthermore, improving soil conditions and fostering collaboration among stakeholders are crucial to ensure sustainable restoration and long-term ecosystem resilience.

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